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NUCLEAR RADIATION---

SOURCES AND IMPACT

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NUCLEAR RADIATION - SOURCES AND IMPACT

I. Introduction

Man has always lived in a background of naturally-occurring radiation. It is only in the last century that we became aware of its presence and began to investigate its effect and impact on human life. Today, man's exposure to radiation comes from both natural background radiation and man-made radioactive materials. Naturally-occurring background radiation is composed of two components: 1) Terrestrial and 2) Extraterrestrial or Cosmic. Man-made radiation originates from x-ray machines, accelerators, and the fission processes in nuclear reactors or nuclear weapon devices.

Man has altered his levels of radiation exposure from both natural and man-made radiation sources. The isolation and purification of naturally-occurring radioactive materials, such as radium and uranium, has resulted in both the opportunity for beneficial use and beneficial impacts while also providing a concentrated source of naturally-occurring radioactive material that could result in substantially increased levels of radiation exposure to those using these materials. The generation of man-made radioactive materials deliberately for special application or their generation as by-products of power generation in either reactors or weapons open similar possibilities.

Today, we are keenly aware of both the beneficial and the harmful impacts of radiation exposure. In fact, it appears clear that more is known about the potential impacts of unwise or uncontrolled use of radiation than about the corresponding impacts of most chemicals or other agents.

Today, we look to the beneficial uses of nuclear fission to meet the requirements for clean sources of power. Such activity gives rise to numerous questions relating to the sources and impacts of radiation, only a few of which will be discussed. Typical questions we frequently hear are:

Will the additional exposure and impact from the nuclear power industry be unacceptable in terms of environmental impacts?

How, or indeed, will man be able and inclined to control radiation exposure resulting from man-made radionuclides?

Can a judgment be made and generally accepted relating to what is the lowest practicable level of radiation exposure for each phase of the nuclear power industry?

How will acceptability and nonacceptability be judged?

Will industry practice keep radiation exposures "as low as practicable" for both occupational exposed individuals and the general public?

What will be the radiation environmental impact of nuclear power and its associated waste management programs?

Can the total environmental impact of all power sources be compared on some common parameters understandable and meaningful to the scientist and the general public alike?

In evaluating the impact of the nuclear power industry, some of the more significant questions are:(1)

What additional inventory of radioactive materials may given activities generate?

What are the greatest concentrations of the most important radionuclides?

How long do such concentrations persist?

How large an area is embraced by the persistently high concentrations?

To what extent do organisms and people come in contact with the most contaminated zones?

What are the resulting annual radiation doses received by organisms and by man?

How long will the contamination remain after the addition to the area has stopped?

How do the radiation doses expected from the nuclear power industry compare with the ever-present naturally-occurring radiation background and other "accepted doses"?

In the debate on the overall safety of the nuclear power industry these questions, which are key in determining actual impact, are rather commonly ignored.

All of these questions need to be examined, debated, and answered. Let's look at some of the data and see what we can summize on both the current and the potential environmental impacts of the nuclear industry and its radioactive waste management programs. Let's look first at the natural background levels, then the U.S. nuclear power industry and the radiation levels that may arise from it. Finally, let's compare these impacts and see how the current and projected radiation doses arising from the U.S. nuclear industry compare with other radiation dose routinely encountered.

While there are some who insist that such comparisons should be made in terms of "health effects" rather than dose units, this presentation follows the lead of the majority of scientists that believe the data to permit calculations of "health effects" are inadequate.

In any event, it appears that most agree that genetically significant "health effects" that may occur from practices in the nuclear power industry (if exposures are kept below natural background levels) will not differ in kind or quantity from those experienced from natural background radiation.[2] By comparing radiation doses directly one can estimate relative impacts between several industrial practices and also compare such impacts to those arising from natural background or other sources of radiation.

Interestingly, even those who use the "health effects" method of impact assessment recognize the lack of specific validated data to convert very low-level radiation doses and dose rates into meaningful "health effects" and recommend only comparing the relative "health effects" between actions or items.[3] In effect then, comparing radiation doses accomplishes the exact objective without introducing the generally unknown "health effects" per given dose relationship factor.

II. Naturally-Occurring Radiation

a. Terrestrial Radiation

Terrestrial radiation gives rise to both external and internal radiation exposure. Terrestrial radiation is emitted from radionuclides contained in varying amounts in all soils and rocks, the atmosphere, the hydrosphere, and from those radionuclides deposited in man by way of his food chains. Terrestrial radiation arises from the radioactive nuclides that belong to one of the three radioactive series - headed up by U-238, U-235, or Th-232, as well as a few nonseries radioactive materials of which K-40 and Rb-87 are the most important. The uranium and thorium series are widely distributed in the earth's crust.

The external radiation dose from these materials is estimated to be about 44 mrad/year, while the internal dose is estimated to total about 20 mrad/year.(4) The typical contributions to the internal dose are K-40 - 19 mrad/year; C-14 - 0.7 mrad/year; Po-210 - 0.06 mrad/year; and Rb-87 - 0.3 mrad/year.

b. Extraterrestrial---Cosmic Ray Radiation

Extraterrestrial or Cosmic Ray bombardment of the earth's upper atmosphere produces human radiation exposure by direct external exposure from secondary produced radiation and through the generation of radioactive materials which then move downward from the upper atmosphere into mans' environment. The Cosmic Ray dose at the earth's surface varies with location on the surface, increasing toward the poles and decreased toward the equator. The altitude above sea level is one of the important factors in determining the Cosmic Ray dose.(4) As the altitude increases, the dose rate doubles about every 1,500 meters for the first few kilometers above the earth's surface. At sea level the cosmic component of natural background radiation is about 30 mrads/year.(4)

Cosmic Ray bombardment produces many radionuclides in the upper atmosphere. Some of the commonly identified Cosmic Ray produced radionuclides are shown in Table I.

TABLE I

Some Cosmic Ray Produced Radionuclides (4)

H-3	Na-24	Si-32	Cl-36
Be-7	Mg-28	P-32	Cl-38
C-14	Al-26	S-35	Ar-39
Na-22	Si-31	S-38	Kr-81

Tritium (H-3) and Carbon-14 (C-14) are probably the most important from a radiation dose point of view. Their annual production rate, equilibrium inventory, and the resulting whole body dose rate from exposure to these radionuclides is given in Table II.

TABLE II

Cosmic Ray Tritium and C-14 Doses (4)

Isotope	Annual Product Rate	Equilibrium Inventory	Whole Body Dose Rate
Tritium	1.6 MCi	28 MCi	0.002 mrad/yr
C-14	0.3 MCi	280 MCi	1 mrad/yr

c. Summary - Naturally-Occurring Radiation

The total external dose from naturally-occurring radioactive materials is about 72 mrad/year while the total internal dose is about 20 mrad/year. The total dose at sea level from naturally-occurring radiation is, on the average, about 94 mrad/year. At higher elevations and in areas of high uranium and thorium content, the naturally-occurring radiation levels may be considerably greater. In the upper Mississippi River basin, naturally-occurring radiation background typically ranges from 130 mrads/year to 150 mrads/year.(5)

III. Man-Made Radiation

a. Atmospheric Nuclear Weapons Testing

Atmospheric testing of nuclear weapons in the 50's and early 60's led to the release of many radionuclides into the environment. The long half-life radionuclides still contribute to mans' radiation dose. The principal longer-lived radionuclides generated by the nuclear weapons testing program are: H-3, C-14, Fe-55, Kr-85, Sr-90, and Cs-137. While there are local variations in the radiation dose from weapons testing fallout, the average for 1970 was about 4 mrad/year for the northern hemisphere.(2)

b. Nuclear Power Industry

1) Nuclear Power Waste

Nuclear power is now generating 25 x 10^6 kilowatts or 5.5% of the U.S. electricity. Today there are 42 nuclear power reactors licensed to operate, 56 under construction, and 101 planned.[6] The nuclear power forecast is shown in Table III.

TABLE III

Nuclear Power Forecast[7]

Date	Percent U.S. Electricity	Millions of Kilowatts	Number of Plants
1970	5.5	25	42
1980	21	132	140
1990	44	508	455
2000	60	1,200	1,000

It is not expected that the total number of fission plants in the U.S. will excess 1,000. By the end of this century, the breeder plants will gradually take over a larger share of the electricity production. Hopefully, at some time in the next century, these plants will be replaced by fusion reactors and solar power stations.[6]

Radioactive wastes are generated in practically all phases of the nuclear power cycle and accumulate as gases, liquids, or solids at widely varying radiation levels. Currently high-level waste from fuel reprocessing plants are stored as liquids in underground tanks. Recent AEC policy requires these wastes to be converted to a solid form within five years of generation and shipped to a Federal repository within ten years of generation.

The inventory of radionuclides in reactors or stored as waste is, of course, highly dependent on the reactor types in operation and the schedule and fraction of the power generated by BWR, LWR, and LMFBR units. As an estimate, only to indicate the quantities of some of the longer-lived radionuclides involved, some typical inventory data is given in Table IV.

TABLE IV

Radionuclide Inventory Generated

Radionuclide	10^6 Ci/1000 MWe
H-3	0.05
Kr-85	1
Ru-106	5
Sr-90	3
Cs-137	9
Pu-239	4
Total Activity	2000

At various times in the future, the inventory of some of the radionuclides generated by the nuclear power reactors in the U.S. might be of the order indicated in Table V.

TABLE V

Possible Radionuclide Inventory
(10^6 Ci)

Year	H-3	Kr-85	Sr-90	Ru-106	I-129	Cs-137	Pu-239
1970	1	30	90	100	2×10^{-11}	200	100
1980	7	200	500	600	1×10^{-10}	1,000	500
1990	30	600	2,000	3,000	5×10^{-10}	5,000	2,000
2000	60	1,000	4,000	6,000	1×10^{-9}	10,000	5,000

The radionuclide inventory generated in the fuel elements is not considered as a reactor waste - but as a fuel reprocessing facility waste. However, each power reactor facility will generate some waste at the reactor site.

Typically, a 1,000 MWe BWR will generate about 3,900 cubic feet of a significant radioactive waste per year. A similar sized PWR will produce about 1,000 cubic feet of packaged waste per year. In addition, some 30 to 50 drums (55 gal) per year of dry solid waste of low contamination level will also be generated. Typically, waste material may be immobilized in cement or similar materials at a ratio of about 1.8 cubic feet of waste per 5.4 cubic feet of cement to a 7.2 cubic feet (55 gal) drum.[8] A 1,000 MWe BWR electric plant will require about 2,000 drums per year while a 1,000 MWe PWR will need about 600 drums/year to handle reactor site waste.

For fuel reprocessing facilities, it is expected that the solidified fission product waste from the processed fuel elements will be placed in canisters measuring 1-foot in diameter and 10-feet in length. Ten such canisters can contain the irradiated-reactor-fuel waste from one year's operation of a 1,000 MWe reactor.[8] For such a system of waste disposal, the waste container quantities needed are shown in Table IV.

TABLE VI

Reactor-Fuel Waste Containers

Year	Waste Canisters
1970	420
1980	1,400
1990	4,500
2000	10,000

2) Environmental Programs

We need to remind ourselves from time-to-time that the quantities of radioactivity released to the environment cannot be related blindly to impact or relative degrees of risk. Where radiological risk assessment is the objective, the concentration data on individual radionuclides, not the total inventory, is required. Also, knowledge on the pathways of movement of radionuclides to man and the biological and physical factors to calculate doses to man are required. Extensive studies have provided substantial information in this area.

To evaluate the impact of radionuclides, we need good environmental surveys to measure the concentrations of radionuclides in the various pathways of exposure and good environmental evaluation programs to calculate the dose impact of the presence of the radionuclides.[9] The basic objectives of environmental survey and evaluation programs are shown in Table VII.

TABLE VII

Purposes of Environmental Programs

1. Radiological Protection of People
2. Fulfill Regulatory Requirements
3. Audit Containment Systems & Effluent Monitoring
4. Maintain Public Acceptance
5. Legal Protection from Liability Actions

The primary consideration should be radiological protection of the public. Secondary reasons are fulfilling regulatory requirements, auditing containment systems and effluent monitoring results. These later two reasons are, however, related to the primary objective since the purpose of regulatory requirements is primarily radiation protection. Two others often mentioned as secondary objectives are both related to public relations---maintaining public acceptance of the nuclear facility and gathering of date for protection against liability claims. In nearly all instances an environmental program designed around the primary objective of radiological protection will satisfy the other objectives or can be made to satisfy them with only slight additions and alterations.

In the early days of the atomic energy program it was not always possible to relate the environmental survey data to a parameter that could be used to express actual population risk. Early programs consisted of sampling and analyzing environmental media, seeking for radioactivity and attempting to explain its presence wherever it was found. Today it is possible to relate radioactivity in the environment to radiation dose to people and thus to evaluate the impact of a nuclear facility in terms of the radiation dose received by residents in the vicinity of the plant.

If the objective of the surveillance program is to ensure that acceptable doses are not exceeded, measurements need to be made which will allow tissue doses to be calculated. It follows that the most profitable measurements will be those which can be made on the materials which provide a direct source of exposure, whether air, water, food or some other material. In certain cases, however, measurements on materials, which do not constitute a direct source of exposure to man but which are good indicators of environmental contamination, can be used to evaluate the trend of this contamination.

Development of the surveillance program needs to start with the facility itself, work through the environmental and population factors operating between the points of releases and the points of public exposure, should consider the potential radiation doses to the public, and then should come full circle back to the facility by relating public exposure to specific release rates of the various radionuclides involved. Table VIII illustrates the evaluation of radiation dose and the related environmental measurements.

The first column in the table lists five principal steps in the process, the second column lists the factors to be considered in each step, the methods of evaluation are given in Column 3, and the last column indicates the standards against which the results of the evaluation are to be compared.

Step A requires a thorough knowledge of the facility and the processes involved. What radionuclides are to be released routinely and in what quantities? How are they to be released? Are the methods chosen for effluent monitoring sufficient to evaluate the potential impact of the routine releases in the environs? What is the potential for accidental release of additional radionuclides or of greater quantities than normal? Will accidental releases be detected accurately and rapidly enough to permit proper environmental assessment and control?

Step B involves knowledge of the environment and the possible interaction of the environment with the released material. Studies of the meteorology, hydrology, and aquatic and terrestrial biology of the environs are required to determine the behavior of the particular chemical and physical forms of the radionuclides released. The behavior after release of course can be monitored by sampling of environmental media such as air, water, foods, soil and sediment.

TABLE VIII

Evaluating Environmental Impacts[9]

	Step	Factors	Evaluation	Standards
A.	Release	Concentration Rate of Release	Measure Effluent	Release Guides
B.	Dispersion, Reconcentration	Meteorology, Biology, Hydrology, Physical and Chemical Forms	Measure Environmental Media - Air, Water, Foods	Fraction of MPC_w or MPC_a (Concentration Factors)
C.	Intake	Air, Concentration, Water, Consumption Food, Rate	Diet Surveys, Studies of the Uses of Environs	FRC Ranges, ICRP - μCi/day
D.	Retention	Percent Uptake, Biological Half-LIfe, Distribution in Body	Bioassay, Whole-Body Counting	MPBB's
E.	Dose	Body Dimensions, QF, DF, Rads/μCi	Calculate Doses to Maximum Individual, Population Average Adult, Child	10-CFR-20 AEC Manual, FRC Reports, NCRP H.B.'s, ICRP H.B.'s

Step C is related to determination of the human factors which influence the impact of the released material. What are the dietary habits of the local population? What are the sources of their food? What recreational habits might affect their exposure? If data are not readily available to answer these questions, then special studies may have to be undertaken to gather them.

The last two steps, Steps D and E, normally involve only paper studies utilizing the data available from the previous steps. From the parameters defined by the ICRP for the Standard Man and the literature data on phsyiological parameters of other ages one can estimate the long-term accumulation of radionuclides in the body from the intakes previously derived. Then the radiation doses can be calculated for comparison with the appropriate guides and standards. Confirmation of retention and accumulation of radionuclides in the body, when these represent a significant fraction of the maximum allowable amounts, can be made through in vivo or whole-body counting of appropriate members of the general public.

Once these doses are estimated, one can proceed back up the last column of the evaluation chart deriving the maximum allowable releases of the radionuclides and establishing the relationship between actual release and potential doses to people. If it turns out that the releases are only a small fraction of those which would result in residents receiving the maximum allowable doses, then environmental monitoring can be limited to a few simple measurements of indicator materials to confirm the effluent monitoring results.

On the other hand, if the releases are such that the radiation doses received by the public will significantly approach the limiting values, then a comprehensive program of sampling and analysis of air, water, foods, soil and external dose rates need to be instituted. The foregoing review in terms of radiation dose and the environmental and human factor influencing the behavior of the radionuclides should have identified the "critical" nuclides and the "critical" pathways of exposure which need to be monitored.

After an environmental monitoring program is established it should be reviewed periodically to ensure that it is properly formulated and that it still is meeting its objectives. Experience may have reaffirmed relationships between quantities released and environmental measurements, allowing for a reduction in the scope of the surveillance program, or the nature and quantities of radionuclides released from the facility may have changed requiring a shift in the emphasis of the environmental program.

3) Radiation Guides and Standards

The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) have been active in the development of standards for protection against ionizing radiation for the past forty years. The Federal Radiation Council (FRC), whose functions were transferred to the Environmental Protection Agency (EPA) when it was established, was involved for over ten years in recommending radiation exposure guidance to Federal agencies. The recommendations of these groups are used as the basis for the Atomic Energy Commission's (AEC) regulatory and health and safety programs.

Table IX illustrates the current radiation standards for the general public as spelled out by the FRC, and the AEC in Title 10 of the Code of Federal Regulations Part 20 (10CFR20). Two sets of limits are quoted---one for controlling the dose to an individual member of the population and the other for the average dose to the general public. The whole-body limit for the general population can be derived from the recommendation that the dose to the gonads be limited to a total of 5000 mrem up to the mean reproduction age of 30 years.

TABLE IX

Radiation Dose Limits for the Public

Body Organ	Individual (mrem/yr)	Population (mrem/yr)
Whole Body	500	170
Thyroid	1500	500
G.I. Tract	1500	500
Bone	1500	500

The ICRP, in their publication 7, have discussed environmental monitoring and have defined the critical population group whose radiation exposure is to be compared against the recommendations for the maximum permissible doses for individual members of the public. Their definition is -

> "The critical group should be identified in such a way that it is representative of the more highly exposed individuals in the population and is as homogenous as practicable with respect to radiation dose; that is, with respect to those factors which affect the dose in the specific case considered."

Guides on Design Objectives for light-water-cooled nuclear power reactors have been proposed by the AEC.(10) These guides propose that radiation and radionuclide emissions from light-water-cooled nuclear reactors should be limited so that individual members of the public living at the site boundary will generally be less than 5% of the dose due to natural background radiation and that the average dose to the public will be less than 1% of natural background radiation. Further details are given on release concentrations. The guidance allows exposures up to 5 mrem/year from radionuclides in liquid effluents and up to 10 mrem/year for noble gases in addition to some concentration guidance. A most significant point frequently overlooked or forgotten is that this guidance is for design purposes and that it applies only to light-water-cooled nuclear power reactors. It is indeed unfortunate that it is all ready being applied to other sources of radiation exposure by both government agencies and industry.

4. Pathways of Environmental Exposure[11]

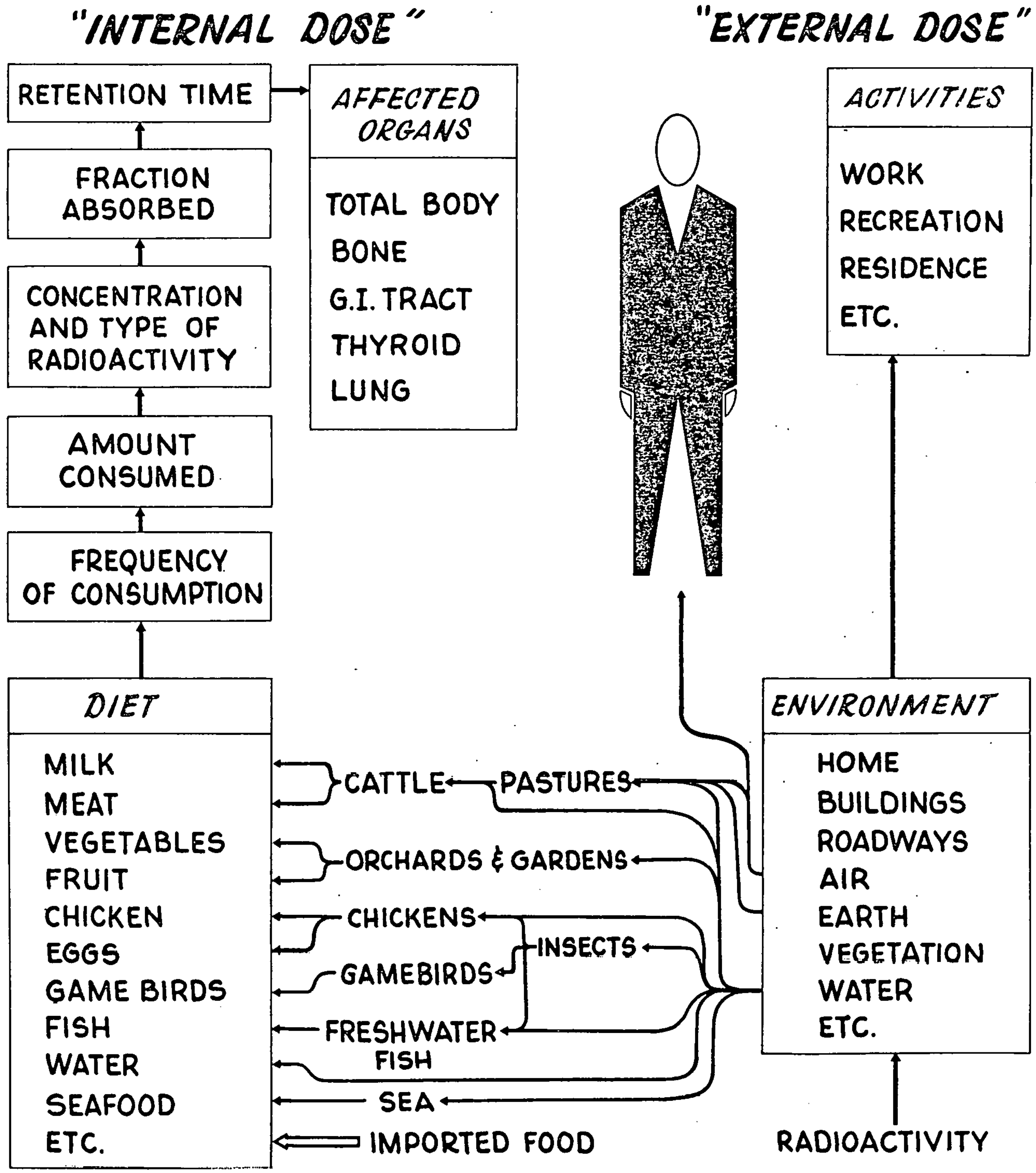
The principal pathways by which radioactive materials released to the environs can reach and expose people are illustrated in Figure 1. Included in this figure are the environmental parameters (Step B) and the human parameters (Step C) mentioned in Table VIII.

External dose can be received from exposure to the cloud of radioactive gases released from a nuclear facility, from swimming or boating in and on waters contaminated from liquid effluents, contact with ground or objects contaminated via deposition from airborne or waterborne radionuclides.

Internal dose can result from inhalation of air or ingestion of water and foods containing the released radionuclides. The pathways by which the foods become contaminated from releases to air and water are also shown. For example, chickens could ingest radioactive materials with their drinking water, with insects, or with feed grown on contaminated ground or irrigated with contaminated water.

Detailed studies of the behavior of radionuclides in the several environmental media are not always available, but much is known at least in general terms about the most important radionuclides. Habits of the local

DOSE CALCULATIONS
PEOPLE LIVING IN AN ENVIRONMENT CONTAINING TRACE AMOUNTS OF RADIOACTIVITY



population which might affect their radiation dose vary with each individual site and should be determined before the environmental survey is designed.

State and Federal agriculture, recreational, and fish and wildlife agencies can be of assistance in defining these parameters. Sometimes special studies of the local population are required, especially if specific critical pathways are involved. Examples of the latter include the consumption of Laverbread by persons in the vicinity of the Windscale facility in the U. K. and consumption of oysters in the vicinity of the Bradwell nuclear power station, U.K.

5) Radiological Impact

The average annual whole body radiation dose from the entire United States nuclear power industry in 1970 was 0.003 millirem. The estimated dose for the year 2000 is 0.426 millirem,(6) less than one-half of one percent of the naturally-occurring radiation background.

The year 2000 study(5) provides a detailed look at the potential radiological impact from the nuclear power industry in the year 2000 on the upper Mississippi and lower Missouri River basins, an area of about 300,000 square miles. The study area has a present population of about 29 million and accounts for about 10% of the

U. S. electricity production and consumption. For purposes of the study the aggregate nuclear generating capacity was taken to be 356,000 MWe consisting of 46,000 MWe of BWRs, 138,000 MWe of PWRs, and 172,000 MWe of LMFBRs, plus 10 nuclear fuel reprocessing facilities. The study results showed that, on the average throughout the region, the potential radiation an average individual could receive in the year 2000 would be increased by about 0.2 mrem/year because of the nuclear facilities. This is only slightly more than 1/10 of one percent of the 140 mrem/year dose received in this area from natural background radiation. Over such a large area, the spread in estimated exposure ranges up to 1.2 mrem/year; about 1% of natural background radiation with only isolated exposures exceeding this value. Some 99% of the population was estimated to receive a potential total body radiation dose of less than 0.5 mrem/year. The pathways of major importance relating to population exposure were governed primarily by air transport rather than by water transport or shipment of foodstuffs. The study concluded that the potential radiation received by the population from the operation of potential nuclear facilities in the year 2000 would present no hazard to their health and safety.

Forseeable waste management programs will not alter these estimates. While there is still debate on the exact plan for the long-term storage of nuclear waste, there is no reason to predict any unfavorable consequences.

There are several plans that can fully meet the required isolation of nuclear waste from mans' environment. The debate is really one of which plan is best in terms of flexibility, in terms of cost and in terms of public confidence and acceptability.

IV. Conclusions

Man receives radiation dose from a variety of sources.

Table X summarizes some of the radiation doses that are currently received by the average U.S. citizen.

TABLE X

Average Annual Doses

Activity	Dose (mrem/year)
Terrestrial Background	44
Cosmic Ray	30
Naturally Internal	20
Medical Services	75
Global Fallout	4
Occupational Exposure	2.6
Nuclear Power - 1970	0.003
Nuclear Power - 2000	0.4

That radiation dose from the nuclear power industry is at the bottom of the list in terms of quantity of dose and consequently in terms of impact on man. Nevertheless, waste management programs throughout the nuclear power industry are designed to keep radiation impact on man at the "as low as practicable" level regardless of the inconsequential impact. Man would do well to practice similar policies on many other environmental impacts from many other industries.

Even in the year 2000 with 1,000 nuclear power plants in operation, the average annual dose from this industry is projected to be less than 0.4% of the unavoidable natural background radiation levels. In fact, the natural background radiation level varies by a far larger percentage as one moves from an area of low natural uranium content to an area of high natural uranium content or from an area of low elevation to one of higher elevation. On the average, a change in altitude of only a few hundred feet in elevation gives an increase in cosmic ray dose about equal to the total radiation dose predicted for the nuclear power industry in the year 2000. An individual who takes just one 2-hour trip in a jet aircraft will receive an extra radiation dose during that 2-hour period that will exceed the annual dose he may anticipate receiving in the year 2000 with a thousand nuclear power plants in operation. It is appropriate to always keep radiation dose as low as practicable and to avoid any release of radionuclides that can practicably be avoided---but let's be realistic in evaluating the impact of the nuclear industry. The impact is so small and so easily exceeded by a multitude of daily accepted practices by the population that undue concern is unrealistic. Who among us would even consider deciding where to live based on soil uranium content, home construction materials or elevation above sea level of one's home and work location? Yet these factors usually have significantly more impact on an individual's annual radiation dose than that predicted from the nuclear power industry in the year 2000. All of us should ask, "Where should we put our time, effort, and money to improve the quality of mans' environment?" The nuclear power industry is about at the bottom of the action-required priority list. Let's make our environment improvement efforts count by placing them where they are needed - where they can make a contribution to better living conditions.

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